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STUDY ON THE USE OF A METHOD FOR DETERMINING AGGREGATE LOT SIZE IN FLEXIBLE MANUFACTURING SYSTEMS WITH A VIEW TO REDUCING MANUFACTURING COSTS

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Abstract: The paper deals with the notion of aggregate batch used in flexible manufacturing systems and presents the way in which the size of the preparation-completion costs that occur when the flexible manufacturing system has to pass from one processing state to another, in order to process the parts included in the batch, vary according to the size of the aggregated batch. The affinity coefficient was used to express the size of the setup cost.

Keywords: flexible manufacturing system, aggregate batch, setup cost, utility theory, graph theory

1 INTRODUCTION

The batching problem is specific to series manufacturing, which starts from the idea that grouping several identical parts in a batch reduces the setup cost.

In flexible manufacturing systems (FMS), due to the attribute of flexibility which implies a great mobility in changing the type of manufacturing and, consequently, low setup costs which is great especially when it comes to external financing (Cordos, RC, 2006), the batch component is no longer so restrictive, admitting different types of parts to fit into certain "limits"(Abrudan and Cândea, 2002):

- close dimensions;
- to use the same set of tools;
- to be made of the same materials;
- not involve large adjustments when switching from the production of one part to the production of another.

Parts grouped in a batch in such a way are called an aggregate batch.

The flexibility of the manufacturing system represents the measure of the system's effort to move from one state to another, in relation to the variation of the production load.

In order to establish the flexibility of the manufacturing system, the degree of affinity can be used, which reflects the degree of typological closeness between the products that will be made in the system. Practically, the degree of affinity will indicate the system's effort to adapt to the types of products to be processed.

The heuristic used to determine the parts that can be grouped in the form of an aggregate batch is called the Method of decomposition into strongly related components (Abrudan and Cândea, 2002).

This method based on graph theory is usually used to determine the input sequence of parts in flexible manufacturing systems in order to process them but, because the principle of the method starts from the grouping of parts depending on their similarity based on affinity coefficients (in which the values of the characteristics of the parts are taken into account), this method can also be used to identify the aggregated batches.

Thus, in the following, only that part of the method aimed at grouping parts based on their similarity will be presented.

2 CASE STUDY ON DETERMINING THE SIZE OF AGGREGATED BATCHES IN A FLEXIBLE MANUFACTURING SYSTEM

It is desired to process 15 straight steel shafts in a flexible manufacturing system, hereinafter referred to as parts, which require several types of processing.

These parts were measured (L), weighed (G) and their rigidity (R) was determined, these data are provided in Table 1.

Table 1 – Characteristics of the parts

Part	**L [mm]**	**G [Kg]**	**R**
R1	126	2,87	2,07
R2	176	5,74	2,41
R3	160	5,08	2,22
R4	127	1,51	2,89
R5	146	4,51	2,06
R6	137	3,88	2,01
R7	112	1,04	2,87
R8	227	12,28	2,41
R9	146	4,01	2,18
R10	162	3,57	2,70
R11	112	1,85	2,15
R12	185	8,38	2,15
R13	125	4,31	1,67
R14	180	6,71	2,31
R15	184	6,51	2,42

Since the characteristics of the parts are expressed through different units of measure, the utility theory will be used to be able to compare the parts with each other based on these characteristics (considered criteria for describing the production load).

Thus, utility "1" will be assigned for the most favorable case within each criterion and utility "0" for the most unfavorable case.

For intermediate values, utilities between "0" and "1" will be obtained by using one of the formulas below: (Cercetări operaționale, 2022)

a). If the favorable cases (utility "1") correspond to the minimum values of the criterion:

$$u_k = \frac{max - a_k}{max - min} \qquad (1)$$

b). If the favorable situations (utility "1") correspond to the maximum values of the criterion:

$$u_k = \frac{a_k - min}{max - min} \qquad (2)$$

where:

u_k = the utility calculated within the criterion considered for part "k";

max, min = maximum and minimum values recorded within the considered criterion;

a_k = value of the criterion considered for part "k";

In the present study, the most favorable case corresponds to the minimum value that will receive utility "1" and the intermediate values will be determined with the formula from case a)., the volumes obtained being centralized in Table 2.

The parts are ranked in descending order, from top to bottom, according to the total processing time on the machines.

Table 2 – Utility values

Part	**L [mm]**		**G [Kg]**		**R**	
8	227	**0,00**	12,28	**0,00**	2,41	**0,39**
14	180	**0,41**	6,71	**0,50**	2,31	**0,47**
12	185	**0,37**	8,38	**0,35**	2,15	**0,60**
15	184	**0,37**	6,51	**0,51**	2,42	**0,38**
2	176	**0,44**	5,74	**0,58**	2,41	**0,39**
10	162	**0,57**	3,57	**0,78**	2,70	**0,15**
9	146	**0,70**	4,01	**0,74**	2,18	**0,58**
3	160	**0,58**	5,08	**0,64**	2,22	**0,54**
6	137	**0,78**	3,88	**0,75**	2,01	**0,71**
5	146	**0,70**	4,51	**0,69**	2,06	**0,68**
13	125	**0,89**	4,31	**0,71**	1,67	**1**
7	112	**1**	1,04	**1**	2,87	**0,01**
1	126	**0,88**	2,87	**0,84**	2,07	**0,67**
4	127	**0,87**	1,51	**0,96**	2,89	**0**
11	112	**1**	1,85	**0,93**	2,15	**0,60**

Since not all criteria are equally important in the description of the production load, importance coefficients will be assigned for these criteria:

$K_G=0,30$, $K_L=0,30$ and $K_R=0,40$

In order to determine the affinity coefficients, the concordance coefficients must first be determined.

The flexibility effort of the FMS when moving from processing one type of part to another is the greater the more the types of parts are typologically distant, a situation reflected by a greater "difference" between the respective parts, a difference given by the coefficient of concordance (which shows the proximity between two types of parts).

Thus, the smaller the concordance coefficient is (greater similarity between parts), the smaller the flexibility effort of the FMS when switching from processing one type of part to another will be (Table 3).

The concordance coefficient will be calculated with the formula "(Abrudan and Cândea, 2002):

$$C(g,h)=\sum_j k_j \cdot \left|u_{gj} \cdot u_{hj}\right| \qquad (3)$$

where:

$C_{(g,\ h)}$ = coefficient of concordance between parts g and h;

g, h = indices of the types of parts between which the concordance is calculated;

j = index of the criterion for describing the production load;

k_j = importance coefficient of criterion j;

u_{gj}, u_{hj} = utilities calculated for parts g and h.

Table 3 – Matrix of the concordance coefficients

	R8	**R14**	**R12**	**R15**	**R2**	**R10**	**R9**	**R3**	**R6**	**R5**	**R13**	**R7**	**R1**	**R4**	**R11**
R8	0	0,307	0,300	0,268	0,309	0,496	0,509	0,430	0,590	0,536	0,724	0,750	0,629	0,703	0,664
R14	0,307	0	0,109	0,053	0,070	0,259	0,203	0,124	0,284	0,230	0,418	0,514	0,323	0,467	0,357
R12	0,300	0,109	0	0,141	0,179	0,368	0,227	0,177	0,290	0,236	0,424	0,623	0,329	0,576	0,365
R15	0,268	0,053	0,141	0	0,045	0,227	0,245	0,166	0,326	0,272	0,460	0,482	0,365	0,435	0,400
R2	0,309	0,070	0,179	0,045	0	0,189	0,200	0,121	0,281	0,228	0,416	0,444	0,320	0,397	0,355
R10	0,496	0,259	0,368	0,227	0,189	0	0,224	0,202	0,298	0,278	0,455	0,254	0,321	0,208	0,355
R9	0,509	0,203	0,227	0,245	0,200	0,224	0	0,079	0,081	0,053	0,231	0,395	0,120	0,348	0,155
R3	0,430	0,124	0,177	0,166	0,121	0,202	0,079	0	0,160	0,106	0,294	0,446	0,199	0,399	0,234
R6	0,590	0,284	0,290	0,326	0,281	0,298	0,081	0,160	0	0,054	0,157	0,422	0,072	0,375	0,165
R5	0,536	0,230	0,236	0,272	0,228	0,278	0,053	0,106	0,054	0	0,188	0,449	0,099	0,402	0,191
R13	0,724	0,418	0,424	0,460	0,416	0,455	0,231	0,294	0,157	0,188	0	0,516	0,172	0,480	0,259
R7	0,750	0,514	0,623	0,482	0,444	0,254	0,395	0,446	0,422	0,449	0,516	0	0,350	0,056	0,257
R1	0,629	0,323	0,329	0,365	0,320	0,321	0,120	0,199	0,072	0,099	0,172	0,350	0	0,308	0,093
R4	0,703	0,467	0,576	0,435	0,397	0,208	0,348	0,399	0,375	0,402	0,480	0,056	0,308	0	0,289
R11	0,664	0,357	0,365	0,400	0,3551	0,3554	0,155	0,234	0,165	0,191	0,259	0,257	0,093	0,289	0

The transition from concordance coefficients to affinity coefficients will be achieved by replacing the values of the concordance coefficients on each line with numbers indicating their ascending order. With these new elements, the preference ranking matrix will be obtained (Table 4) and its elements are named affinity coefficients.

Table 4 – Matrix of the preference rankings

	R8	**R14**	**R12**	**R15**	**R2**	**R10**	**R9**	**R3**	**R6**	**R5**	**R13**	**R7**	**R1**	**R4**	**R11**
R8	0	3	2	1	4	6	7	5	9	8	13	14	10	12	11
R14	9	0	3	1	2	7	5	4	8	6	12	14	10	13	11
R12	8	1	0	2	4	11	5	3	7	6	12	14	9	13	10
R15	7	2	3	0	1	5	6	4	9	8	13	14	10	12	11
R2	9	2	4	1	0	5	6	3	8	7	13	14	10	12	11
R10	14	7	12	5	1	0	4	2	9	8	13	6	10	3	11
R9	14	7	9	11	6	8	0	2	3	1	10	13	4	12	5
R3	13	4	7	6	3	9	1	0	5	2	11	14	8	12	10
R6	14	8	9	11	7	10	3	5	0	1	4	13	2	12	6
R5	14	8	9	10	7	11	1	4	2	0	5	13	3	12	6
R13	14	8	9	11	7	10	4	6	1	3	0	13	2	12	5
R7	14	11	13	10	7	2	5	8	6	9	12	0	4	1	3
R1	14	10	11	13	8	9	4	6	1	3	5	12	0	7	2
R4	14	11	13	10	7	2	5	8	6	9	12	1	4	0	3
R11	14	11	12	13	9	10	2	5	3	4	7	6	1	8	0

It is mandatory to check if the concordance coefficients can be replaced by the affinity coefficients, if so, the latter can be used as a measure of the flexibility effort of the FMS (materialized through a transition cost). Thus, the correlation between the concordance coefficients and the affinity coefficients must be determined by means of linear regression.

The correlation coefficient shows the intensity of the connection between the two types of coefficients and can take values between "-1" and "+1". The closer it is to the value "+1", the more intense the connection between the two types of coefficients. If the values are positive the link is direct, if they are negative the link is inverse. (Maniu, 2022)

Based on tables 3 and 4, the points in Figure 1 are generated (each point corresponds to a pair of values from the two tables, one value from one table and another from the other table) and the link propagated by these points is shown by the regression line which has the equation:

$$y = 21{,}293 \cdot x + 0{,}9083 \qquad (4)$$

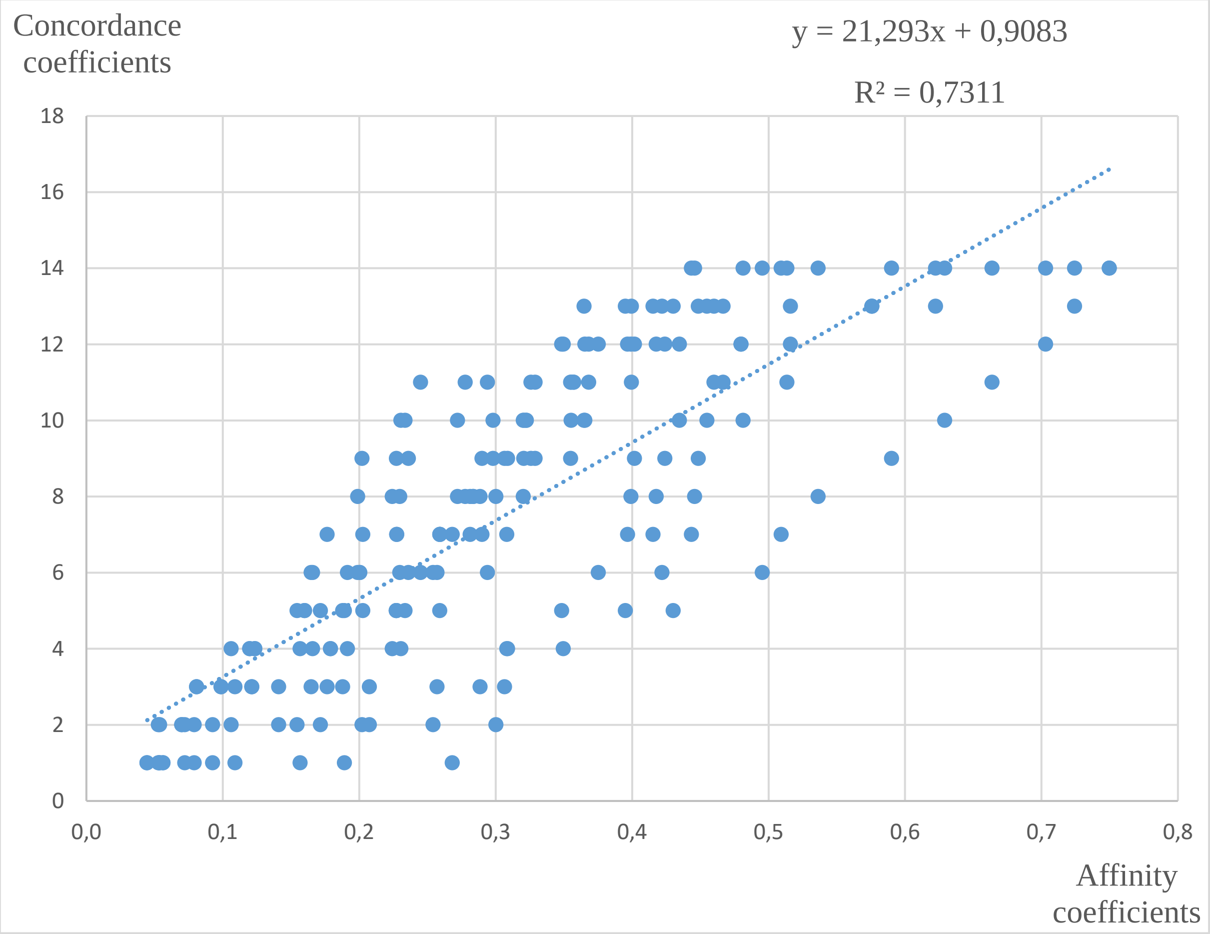

Figure 1 – The points generated by the pairs of values from tables 3 and 4 for each position in the matrix (less the main diagonal) and the regression line generated by them

The result was $R^2 = 0.7311$, meaning that the correlation coefficient "ρ" = 0.855, which proves that the connection between the two types of coefficients is intense and direct, so the concordance coefficients can be replaced by the affinity coefficients.

The R^2 value, the regression line equation and the values of the coefficients from this equation were determined using the Microsoft Office Excel software, but other statistical programs such as SPSS and Minitab can also be used. Usually, the statistical method used to determine the values of the coefficients from the regression line equation is The least-squares method. (Oţel, 2023)

The first stage of the heuristic consists in invalidating the arcs (corresponding to an affinity coefficient of a certain size) that we consider the system transition is not possible, due to the great effort of flexibility that their passage by the system implies. It will start by removing the arcs greater than "1", then with those greater than "2" and so on. It will start from the matrix of connections (Table 5) in which the number "1" will be inserted where there is a connection (between a part on the line and one on the column).

For reasons strictly related to the length of the paper, in the following, only the tables corresponding to the variant in which the arcs with a size greater than "3" are eliminated will be presented in detail, for the rest of the variants being illustrated only the content of the strongly related components obtained, meaning the parts contained by these. In this variant, we assume that there is no possibility of FMS transition along arcs with a size greater than "3".

Table 5 – Matrix of connections, first version

	R8	**R14**	**R12**	**R15**	**R2**	**R10**	**R9**	**R3**	**R6**	**R5**	**R13**	**R7**	**R1**	**R4**	**R11**	**V1'**
R8		1	1	1												
R14			1	1	1											
R12		1		1				1								
R15		1	1		1											
R2		1		1				1								
R10					1			1						1		
R9								1	1	1						
R3					1		1			1						
R6							1			1			1			
R5							1		1				1			
R13									1	1			1			
R7						1								1	1	
R1									1	1					1	
R4						1						1			1	
R11							1		1				1			
V1		**1**	**1**	**1**	1		1	1	1	1			1		1	

$$C1 = (V1 \cap V1') \cup \{R8\} \qquad \rightarrow \qquad C1 = \{R8\}$$

Table 6 – Matrix of connections, second version

	R14	**R12**	**R15**	**R2**	**R10**	**R9**	**R3**	**R6**	**R5**	**R13**	**R7**	**R1**	**R4**	**R11**	**V2’**
R14		1	1	1											1
R12	1		1				1								**1**
R15	1	1		1											**1**
R2	1		1				1								**1**
R10				1			1						1		1
R9							1	1	1						1
R3				1		1			1						1
R6						1			1			1			1
R5						1		1				1			1
R13								1	1			1			1
R7					1								1	1	1
R1								1	1					1	1
R4					1						1			1	1
R11						1		1				1			1
V2	**1**	**1**	**1**	**1**		1	1	1	1			1		1	

$C2 = (V2 \cap V2') \cup \{R14\} \quad \rightarrow \quad C2 = \{R14, R12, R15, R2, R9, R3, R6, R5, R1, R11\}$

Table 7 – Matrix of connections, the third version

	R10	**R13**	**R7**	**R4**	**V3'**
R10				1	1
R13					
R7	1			1	**1**
R4	1		1		**1**
V3	1		1	**1**	

$C3 = (V3 \cap V3') \cup \{R10\} \quad \rightarrow \quad C3 = \{R10, R7, R4\}$

$C4 = \{R13\}$

Therefore, the way in which the parts can be grouped on strongly related components, meaning in aggregated batches, according to the 7 variants obtained by removing arcs above a certain size, is shown in Table 8.

Table 8 – The content of the strongly related components according to the removed arcs

Arches removed over	**Strongly related components**			
1	C1={R8} C2={R14} C3={R12}	C4={R15, R2} C5={R10} C6={R9, R5}	C7={R3} C8={R6} C9={R13}	C10={R7, R4} C11={R1} C12={R11}
2	C1={R8} C2={R14, R15, R2} C3={R12} C4={R10, R9, R3, R6, R5, R1 si R11}			C5={R13} C6={R7, R4}
3	C1={R8} C2={R14, R12, R15, R2, R9, R3, R6, R5, R1, R11} C3={R10, R7, R4} C4={R13}			
4	C1={R8} C2={R14, R12, R15, R2, R9, R3, R6, R5, R13, R1 si R11} C3={R10, R7, R4}			
5	C1={R8} C2={R14, R12, R15, R2, R10, R9, R3, R6, R5, R13, R7, R1, R4 si R11}			
6	C1={R8} C2={R14, R12, R15, R2, R10, R9, R3, R6, R5, R13, R7, R1, R4 si R11}			
7	C1={R8, R14, R12, R15, R2, R10, R9, R3, R6, R5, R13, R7, R1, R4 si R11}			

3 CONCLUSIONS

The flexibility of an FMS is a measure of the system's effort to move from one state to another, in relation to the variation of the production load. Therefore, flexibility is very important because it allows the processing of some parts that are different, grouped in aggregate batches, at low setup costs. However, these parts must fall within certain limits in terms of processing.

The greater the flexibility, the higher these costs will increase. In the paper, flexibility is reflected through the affinity coefficient. An affinity point represents a cost related to the transition from processing one type of part to processing another type of part. Thus, it follows from Table 8 that as the affinity coefficient increases, the aggregated batch will contain more and more types of parts. Considering the extremes in this table, it can be observed that when the affinity coefficient has the value "1", there will be 3 aggregated batches narrowed from the point of view of the types of parts contained: the first batch consisting of the parts R15 and R2, the second batch with R9 and R5, the third batch with R7 and R4.

When the affinity coefficient has the value 7, which means a cost 7 times higher than the version above, all 15 parts can be considered as an aggregate batch.

From here it could be concluded, that as long as the parts follow the 4 initial conditions necessary to be able to be grouped in an aggregate batch, the size of the aggregate batch is finally established by the user of the flexible manufacturing system according to his perception regarding to the size of the setup costs.

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